Cardiac Ultrasonography in Structural Abnormalities and Arrhythmias

Recognition and Treatment

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Fetal cardiac ultrasonography has become an important tool in the evaluation of fetuses at risk for cardiac anomalies. It can both guide prenatal treatment and assist the management and timing of delivery. We recommend that a fetal echocardiogram be done when there is a family history of congenital heart disease; maternal disease that may affect the fetus; a history of maternal drug use, either therapeutic or illegal; evidence of other fetal abnormalities; or evidence of fetal hydrops. The optimal timing of evaluation is 18 to 22 weeks' gestation. An entire range of structural cardiac defects can be visualized prenatally, including atrioventricular septal defect, ventricular septal defect, cardiomyopathy, ventricular outlet obstruction, and complex cardiac defects. The outcome for a fetus with a recognized abnormality is unfavorable, with less than 50% surviving the neonatal period. Fetal cardiac arrhythmias are also a common occurrence, 15% in the series described here. Premature atrial or ventricular contractions are most commonly seen and usually require no treatment. Supraventricular tachycardia can result in hydrops and require in utero treatment to prevent fetal demise. Complete heart block, particularly in association with structural heart disease, has a poor prognosis for fetal survival.

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Cardiac ultrasonography in fetuses at risk has assumed a major role in the diagnosis and treatment of prenatal disorders. Structural defects occur in about 8 of 1,000 live newborns[1,2] and more frequently in other situations, making cardiac defects one of the more common fetal abnormalities. The development of high-resolution ultrasound scanners that provide two-dimensional imaging, real-time directed M mode, Doppler, and color Doppler capabilities[3] has enabled structural defects,[4-17] arrhythmias,[18-24] and abnormal cardiac function[25-29] to be recognized in fetuses as early as 16 to 18 weeks. The presence of substantial cardiac defects may determine the site and route of delivery that is best for both fetus and mother. In addition, the availability of high-resolution cardiac ultrasonography adds to the scope of genetic counseling, including the possibility of therapeutic abortion in certain patients, and allows the monitoring of arrhythmias during the administration of antiarrhythmic agents, either transplacentally or directly. As advances in cardiac surgical procedures present the possibility of fetal cardiac operations, prenatal cardiac ultrasonography will be of even greater importance.[30-32]

Methods

Indications for Fetal Cardiac Ultrasonography

We use the following indications for fetal echocardiography[15]:

- *Previous occurrence of congenital heart disease in siblings or parents.* If more than one child has been affected previously, or if the mother or father also has congenital heart disease, then the rate of recurrence increases.[33-35]
- *Maternal diseases known to affect the fetus,* such as diabetes mellitus or connective tissue disease, are important indications for fetal echocardiography. For instance, euglycemic control at the time of conception and in early pregnancy may reduce the risk of cardiac maldevelopment and of fetal diabetic cardiomyopathy, which can be recognized before or after birth.
- *Maternal drug use.* Many drugs give rise to fetal abnormalities, including cardiac abnormalities, when ingested during pregnancy. These include alcohol, lithium carbonate, antitumor drugs, certain anticonvulsants, and warfarin sodium.[36]
- *Abnormalities of other fetal systems,* such as chro-

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mosomal abnormalities, diaphragmatic hernia, omphalocele, polyhydramnios or oligohydramnios, and other systemic anomalies, are indications for fetal echocardiography. When other fetal abnormalities have been detected by obstetric ultrasound examination,[37] especially nonimmune hydrops, omphalocele, or diaphragmatic hernia, structural cardiac defects are more frequently detected. Information derived from fetal echocardiography has a direct bearing on care during the pregnancy. In a cohort of 3,016 pregnancies, Smythe and co-workers found 170 fetuses with heart disease, of which 55 (32%) had extracardiac abnormalities and 45 (28%) had chromosomal disease.[38]

• *Hydrops, nonimmune hydrops.* Many fetuses referred for nonimmune hydrops (16.5% to 22.0%) have cardiac disease as well.[25,39,40] Hydrops has a low incidence of survival, particularly with cardiac disease; Smythe and associates reported fatalities in seven of seven cases of nonimmune hydrops with cardiac disease.[38]

• *Abnormalities of fetal heart rhythm: tachycardia or*

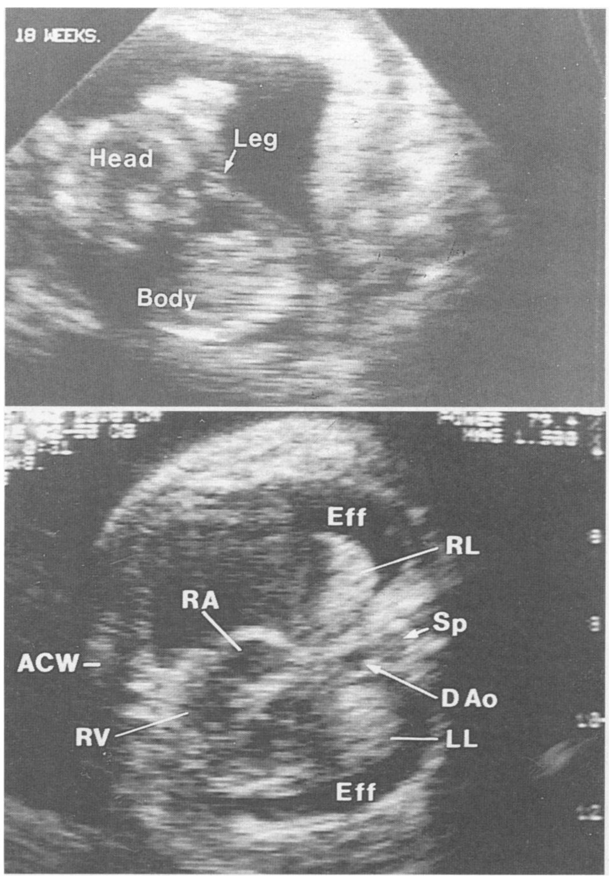

Figure 1.—**Top,** An unmagnified sonographic view is shown of the fetus lying within the uterine cavity at 18 weeks' gestation. The head, legs, and body can be seen clearly, and the orientation of the heart is established in the thorax by referring to its position with regard to the fetal lie. **Bottom,** A magnified transverse ultrasonographic view through the fetal heart (four chambers) and thorax is shown in a fetus with nonimmune hydrops and pleural effusions **(Eff)** surrounding the right lung **(RL)** and left lung **(LL)**. The right ventricle **(RV)** is seen close to the anterior chest wall **(ACW)**, whereas the left atrium lies more posteriorly in front of the descending aorta **(D Ao)** and the spine **(Sp)**. The right atrium **(RA)** lies behind the right ventricle **(RV)**. In this and most subsequent echocardiographic images, a centimeter scale marker is shown to the right of the figure.

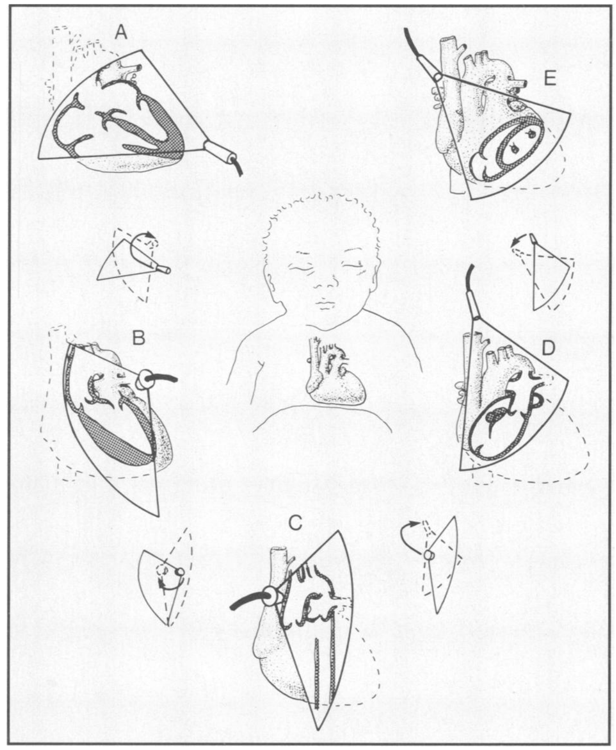

Figure 2.—The drawing schematically represents various views used to image the fetal heart. The heart is oriented more horizontally than after birth (center). Although all views show imaging through the abdomen, this is possible from the back. **A,** A 4-chamber view shows both atria and ventricles and the atrioventricular valves. **B,** The long-axis view shows the left ventricular outflow tract. **C,** Sagittal views show the pulmonary bifurcation, the aortic arch, and the ductal arch. **D,** Short-axis images allow visualization of the right ventricular outflow tract. **E,** Apical short-axis planes show the ventricular structure and the papillary muscles of the left ventricle (from Schmidt and Silverman, reprinted with permission[48]).

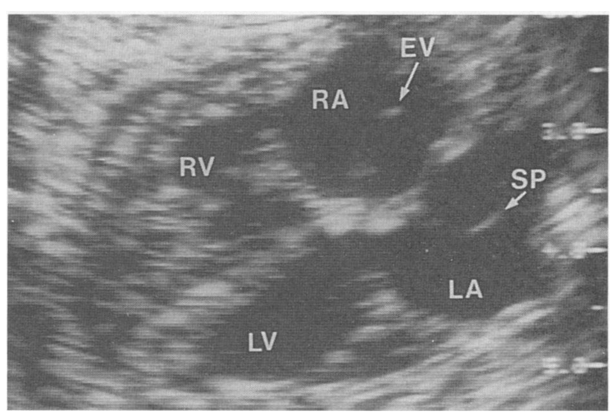

Figure 3.—This fetal 4-chamber view is similar to the plane of Figure 2-A and demonstrates the cardiac chambers and the eustachian valve **(EV)** within the right atrium **(RA)** and the septum primum **(SP)** within the left atrium **(LA)** (from Schmidt and Silverman, reprinted with permission[49]). **LV** = left ventricle, **RV** = right ventricle

bradycardia. Congenital heart block is likely in the presence of a slow fetal heart rate (< 80 beats per minute). To evaluate the arrhythmia and to detect structural cardiac defects, if present, fetal echocardiography should be performed. In association with structural cardiac defects, complete heart block has an extremely poor prognosis, presumably because of the adverse interaction of structural defects and bradycardia. The mothers of fetuses with complete heart block, but without structural cardiac defects, frequently are afflicted with a connective tissue disorder, either overt or covert clinically.[24,41,42] This can be substantiated by obtaining maternal serum specimens for anti-Ro and anti-La antibodies or anti-DNA antibodies, which have been found in a variety of collagen vascular diseases that produce congenital heart block. In our experience, other arrhythmias have no higher association with any structural abnormality of the heart.[24] Tachycardias in utero are associated with heart failure, nonimmune hydrops, and fetal loss. The transplacental administration of antiarrhythmic drugs has proved to be of substantive value for the survival of these fetuses.

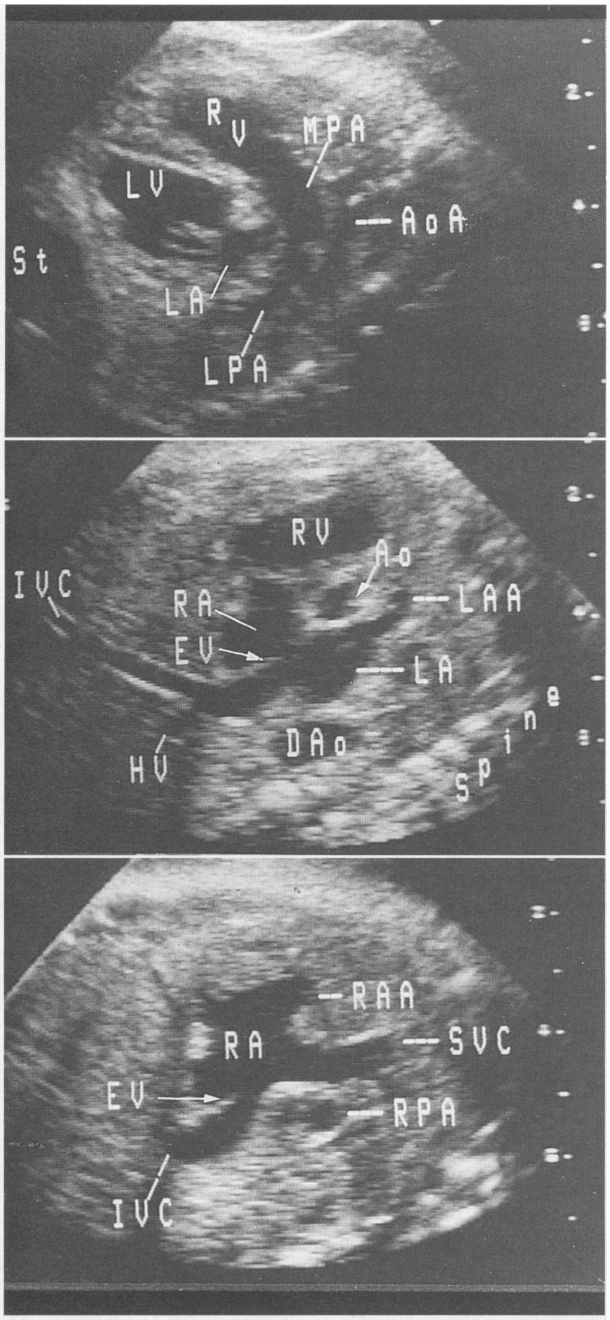

Figure 4.—These images represent a sweep in the sagittal plane from left to right. **Top,** The most leftward cut shows the right ventricle **(RV)** connected to the main pulmonary artery **(MPA)** and the proximal left pulmonary artery **(LPA)**. The left atrium **(LA)**, left ventricle **(LV)**, and a portion of the aortic arch **(AoA)** can be seen, but their connections are not clear. **Middle,** A midline view (note **Spine** to the right) shows the inferior vena cava **(IVC)** and hepatic veins **(HV)** connecting to the right atrium **(RA)**, and the right venous valve or eustachian valve **(EV)**. The left atrium **(LA)**, with its fingerlike appendage **(LAA)**, and the ascending **(Ao)** and descending **(DAo)** aorta and right ventricle **(RV)** are also visualized. **Bottom,** Furthest to the right can be seen both the superior **(SVC)** and inferior **(IVC)** vena cavae draining into the right atrium **(RA)**, with its broad atrial appendage **(RAA)**. A cross-section of the right pulmonary artery **(RPA)** is seen posterior to the SVC (from Schmidt et al, reprinted with permission[50]). **St** = stomach

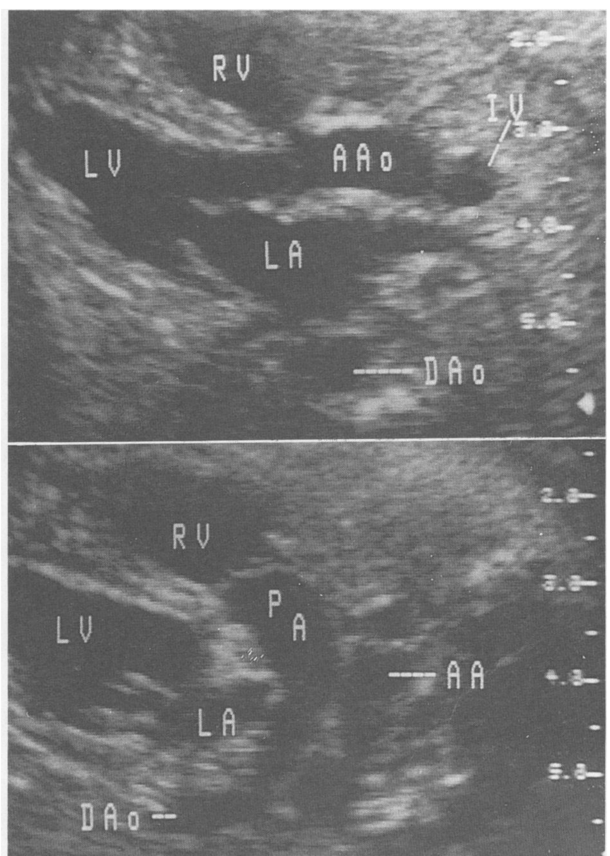

Figure 5.—Long-axis images allow imaging of the ventriculoarterial anatomy (see Figure 6). **Top,** A standard long-axis image shows the entire left system. The left atrium **(LA)** drains to the ventricle **(LV)**, which gives rise to the ascending aorta **(AAo)**. The innominate vein **(IV)** and descending aorta **(DAo)** are seen in cross-section, as is a portion of the right ventricle **(RV)**. **Bottom,** A more leftward image shows the right ventricle **(RV)** connecting to the pulmonary artery **(PA)** inferior to the aortic arch **(AA)** (from Schmidt et al[50]).

When to Perform a Fetal Echocardiogram

We prefer to do an elective evaluation between 18 and 22 weeks' gestation because the valves are well developed, the heart is of adequate size for study, and the fetal size and position usually allow the best access to the heart. Although the incidence of successful imaging is less than at 18 to 22 weeks, successful echocardiographic examination of the heart can be done as early as the 16th week. Intravaginal ultrasound transducers may provide excellent imaging even earlier. If the mother must terminate the pregnancy because of a major abnormality, this information needs to be imparted before the 24th week of the pregnancy.

Equipment

The cornerstone of fetal echocardiography is a high-resolution ultrasound imaging system equipped with M-mode, pulsed Doppler, continuous wave, and color flow Doppler ultrasound. Doppler ultrasonic energy should be kept at or below 100 mW per cm^2 (spatial peak-temporal average), and Doppler interrogation should be limited to as short a time as possible.[43,44]

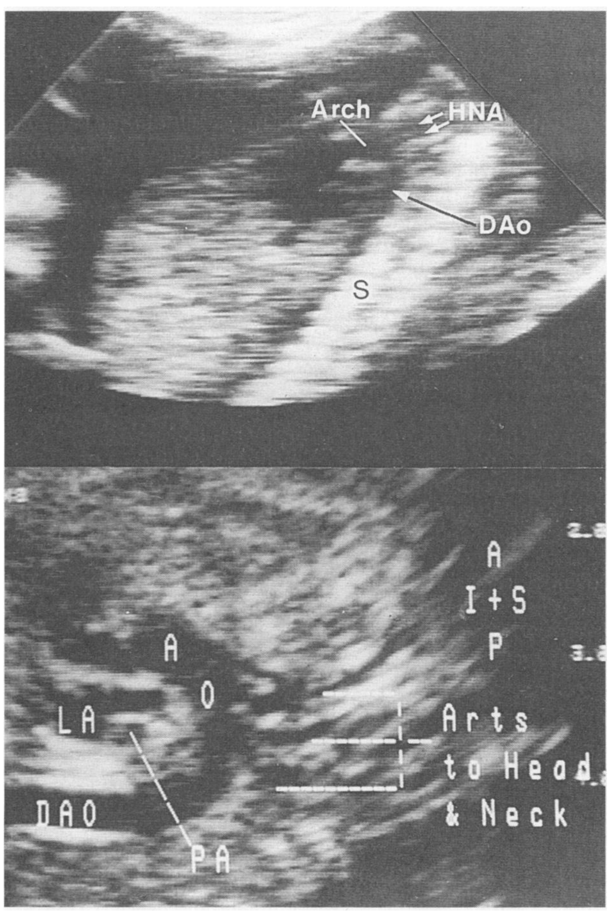

Figure 6.—The top frame shows the entire aortic arch and descending aorta **(DAo)** lying anterior to the spine **(S)**. The vessels to the head and neck **(HNA)** can be seen arising from the superior surface. The bottom frame shows a larger view of the arch. The three arteries to the head and neck are clearly visualized. The left atrium **(LA)** and right pulmonary artery **(PA)** can be seen in the concavity of the arch. Note that the "ductus arch" cannot be seen in this view. **Ao** = ascending aorta

Examination Technique

Cross-sectional Scanning

To define the cardiac position and site, the cross-sectional image must be oriented to the fetal body by noting the position of the head, body, and limbs. An estimated fetal age, using biparietal diameter or femoral length measurements, is also important because cardiac dimensions relate to gestational age and fetal weight.[5,45-47] Imaging the heart through the fetal abdomen usually provides the highest resolution (Figures 1 through 8[48-50]); however, this imaging can be done through the back and rib cage because the fetal lungs are filled with fluid and thus do not generate echo reflections as they do postnatally.

Doppler Color Flow Mapping

Recently the use of color flow mapping has added another dimension to cardiac evaluation,[3] allowing the rapid detection of stenotic or regurgitant jets and thereby diminishing the time required for Doppler interrogation. Different techniques from postnatal echocardiography are used to define the low-velocity signals found in many of the fetal chambers and vessels, as the amount and velocity of flow are substantially less.

Doppler Echocardiography

Pulsed Doppler echocardiography is obtained from the real-time scan with superimposed Doppler color flow imaging. Doppler interrogation within vascular structures

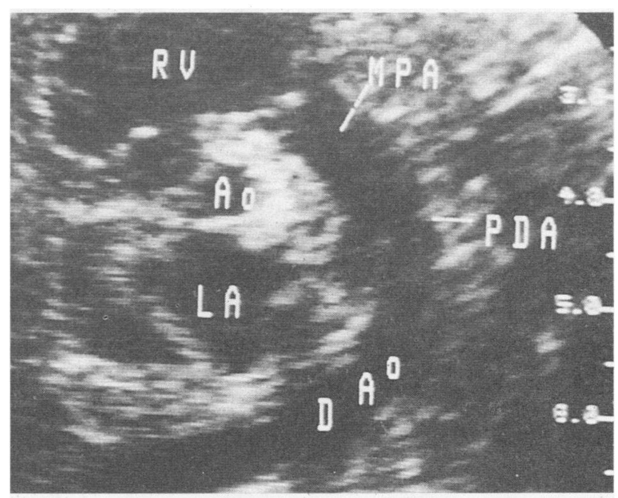

Figure 7.—A magnified fetal sagittal view at 36 weeks' gestation shows the continuation of the main pulmonary artery **(MPA)**, ductus arteriosus **(PDA)**, and descending aorta **(DAo)**, the so-called ductus arch. The ascending aorta **(Ao)** is seen in cross-section; the origin of the left pulmonary artery branch is seen, but the main continuation of the ductus continues as an arch into the descending aorta. Note that the ductus at this stage of gestation appears to be narrower than the caliber of pulmonary artery or the descending aorta. The other structures identified in this view are the right ventricle **(RV)** and a small portion of the left atrium **(LA)**.

identifies arterial or venous flow (Figures 9 and 10) and defines the direction of blood flow in complex cardiovascular malformations. Normal flow velocity profiles have been defined in the fetus across both the atrioventricular and the semilunar valves.[51-57] As after birth, when the velocity of the pulsed-mode Doppler is exceeded, we use continuous-mode Doppler to define the peak velocity for assessing pressure drops across stenotic or regurgitant valves.

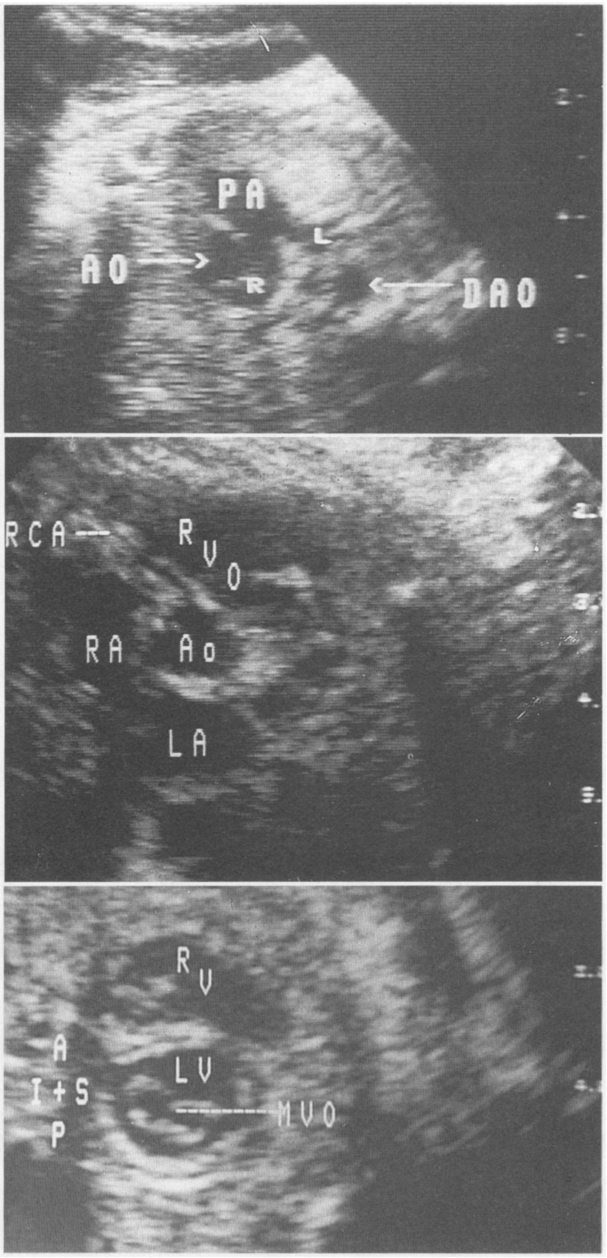

Figure 8.—**Top,** Short-axis views at the base of the heart show the aortic root **(AO)** and the pulmonary artery **(PA)** with its bifurcation into the right **(R)** and left **(L)** pulmonary arteries. The descending aorta **(DAO)** is seen in cross-section behind the bifurcating pulmonary branches. **Middle,** This image is similar to a postnatal short-axis view and shows the right ventricular outflow tract **(RVO)** surrounding the aorta **(Ao)**, with the right coronary artery **(RCA)** in the normal position. **Bottom,** After magnification (3×), this frame shows focus on the heart, which lies between 2.5 and 4.5 cm away from the transducer. The cardiac structures are better demonstrated than above; the left ventricle **(LV)**, the mitral valve orifice **(MVO)**, and the right ventricle **(RV)** can be identified (from Schmidt et al[50]). **LA** = left atrium, **RA** = right atrium, **A** = anterior, **I** = inferior, **P** = posterior, **S** = superior

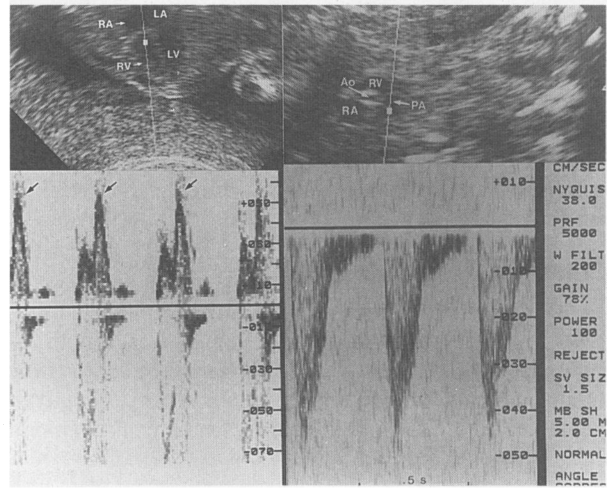

Figure 9.—A pulsed Doppler evaluation of the atrioventricular **(left)** and semilunar **(right)** valves. **Left,** The top portion shows a 4-chamber view with the sample volume **(box)** below the tricuspid valve in the right ventricle **(RV)**. The spectral display **(bottom)** shows a normal Doppler signal. The signal is biphasic with a large a wave **(arrows)** due to atrial contraction preceded by a smaller v wave due to rapid filling. The mirror image below the baseline is an artifact. **Right,** Pulmonary artery **(PA)** evaluation is done from the short axis, which also shows the aorta **(Ao)**, right atrium **(RA)**, and right ventricle **(RV)**. The sample volume (box) is always distal to the valve and here is in the main pulmonary artery. The spectral display shows a classic arterial Doppler signal-pulsatile flow with a small amount of diastolic flow (from Schmidt and Silverman[48]).

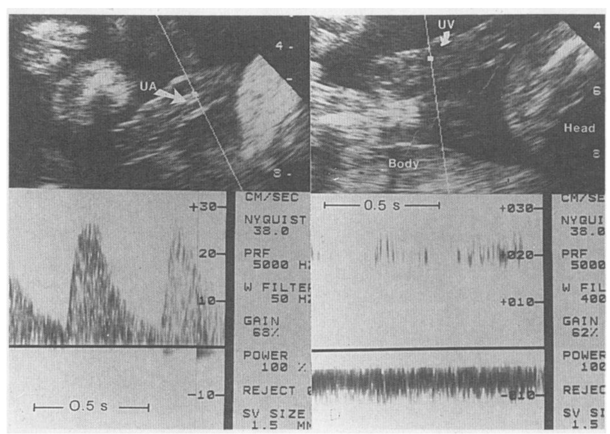

Figure 10.—A pulsed Doppler interrogation of the umbilical cord also provides important hemodynamic information. **Left,** The Doppler sample volume lies within the umbilical artery **(UA, arrow)**. In the lower panel, a characteristic umbilical arterial signal is displayed above the baseline showing flow toward the transducer. **Right,** The Doppler sample volume is within the umbilical vein **(UV, arrow)**; the fetal body and head are also seen. In the lower panel, a Doppler signal of uniformly low velocity throughout systole and diastole is demonstrated below the baseline. The blank space between the baseline and Doppler signal is the result of a high wall-filter setting (from Schmidt and Silverman[48]).

M-Mode Echocardiography

M-mode echocardiography in the fetus is particularly useful for defining cardiac arrhythmias and for measuring cardiac dimensions and wall thicknesses[18-24,45,46] (Figure 11). It is done using a real-time–directed beam to ensure the accurate assessment of wall and valve motion.

Findings

Detection of Fetal Heart Abnormalities

We found a structural cardiac abnormality in 135 (9%) cases among more than 1,500 fetal examinations (Table 1). Isolated cardiac rhythm disturbances were present in 17%.

Atrioventricular septal defect (atrioventricular canal defect) was the commonest serious structural abnormality we found (Figure 12). This defect often was part of a complex cardiac lesion that included left atrial isomerism, complete heart block, and nonimmune hydrops or in association with chromosomal abnormalities. In all, 85% died either in utero or during the neonatal period.

Ventricular septal defects were found as isolated phenomena as frequently as were atrioventricular septal defects (Figure 13) (Table 1). We have observed apparent spontaneous closure of a ventricular septal defect on two follow-up examinations when the lesion was an isolated phenomenon. An isolated ventricular septal defect may be difficult to detect because interventricular shunting is minimal and bidirectional as a result of similar ventricular pressures (Figure 13).

We have encountered nine cases of cardiomyopathy, more often with dilated, poorly contracting ventricles and atrioventricular valve regurgitation associated with fetal hydrops.[58] One fetus presenting with hypertrophic cardiomyopathy was identified to have the Noonan syndrome at birth. Two fetuses appeared to have normal cardiac function at 20 weeks' gestational age, but were found to have dilated cardiomyopathy shortly after birth, suggesting that it is a difficult disease to diagnose prenatally and that myocardial dysfunction may occur either after examination in utero or after birth as in some of our observations.

Several forms of complex cardiac defects that involve a single functioning ventricle have been detected. Most commonly this is in a hypoplastic left heart complex with aortic or mitral atresia (Figure 14).[59] Although the classic case of the absent left ventricle is usually an uncomplicated diagnosis, variants of this lesion may present diagnostic and management dilemmas. These include fetuses with a small left ventricle, endocardial fibroelastosis, and

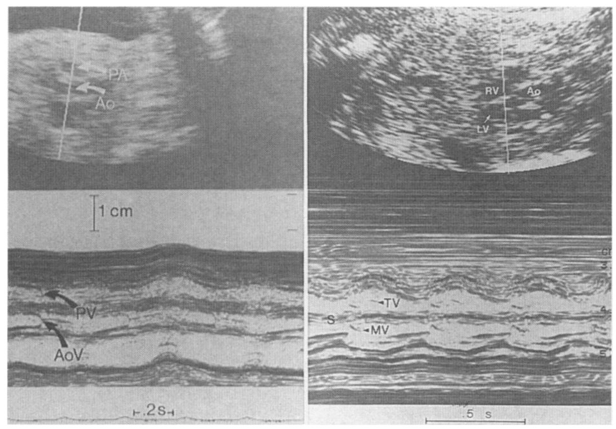

Figure 11.—Real-time–directed M-mode ultrasonogram allows an assessment of the timing of atrial and ventricular events. **Left,** In the top frame, the M-mode cursor has been passed through the fetal thorax, the pulmonary artery **(PA)** and its valve, the aorta **(Ao)** and its valve **(arrows),** and the left atrium posteriorly. The bottom frame shows the opening of the aortic valve **(AoV)** and the pulmonary valve **(PV)** within their respective ventricles. The left atrium and the corresponding atrial contraction can be seen by the changing size of the left atrium as contributed to by the left atrial wall contraction. **Right,** In the top frame the M-mode cursor line crosses the right **(RV)** and left ventricle **(LV)** seen in long axis. In the bottom frame, the M-mode recording shows normal movement of both ventricular walls in systole. Tricuspid **(TV)** and mitral valve **(MV)** motion is also seen. The ventricular septum **(S)** and both ventricular free walls have about the same thickness (from Schmidt and Silverman[48]).

TABLE 1.—*Cardiac Structural Abnormalities and Survivors After Fetal Ultrasonography (N > 1,500)*†*

Abnormality	*Percent of Total*	*Survivors, % of Defects*
Atrioventricular septal defect, including 4 with left atrial isomerism and CHB	1.5	18.2
Ventricular septal defect (VSD), including 1 with left atrial isomerism and CHB	1.5	45.5
Cardiomyopathy, including 3 with familial disease	0.9	28.6‡
Pulmonary atresia or stenosis without VSD	0.8	33.3
Double-outlet right ventricle, including 1 with pulmonary stenosis	0.7	0
Hypoplastic left heart syndrome	0.7	0
Univentricular atrioventricular connection, 3 left-sided, 1 right-sided	0.5	0
Ebstein's anomaly	0.4	0
Aortopulmonary transposition with VSD	0.3	0
Truncus arteriosus tetralogy of Fallot	0.3	0
Multiple rhabdomyoma	0.3	50.0
Thoracopagus	0.4	0
Others	1.1	37.5
Total	9.4	

CHB = complete heart block

*From Silverman.[15] †Based on data available in 1988. ‡One after heart transplant at 6 months of age.

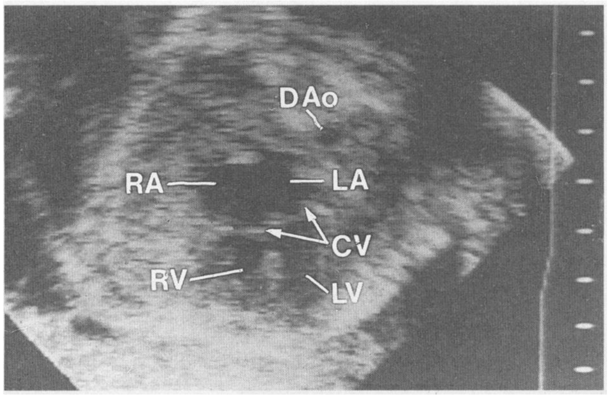

Figure 12.—This example of a 4-chamber view of a fetus with an atrioventricular septal defect shows the common atrioventricular valve **(CV)** straddling the left and right atria **(LA, RA)** and the left and right ventricle **(LV, RV)**. The fetus was 18 weeks' gestation at the time the image was made (from Schmidt and Silverman[48]). **DAo** = descending aorta

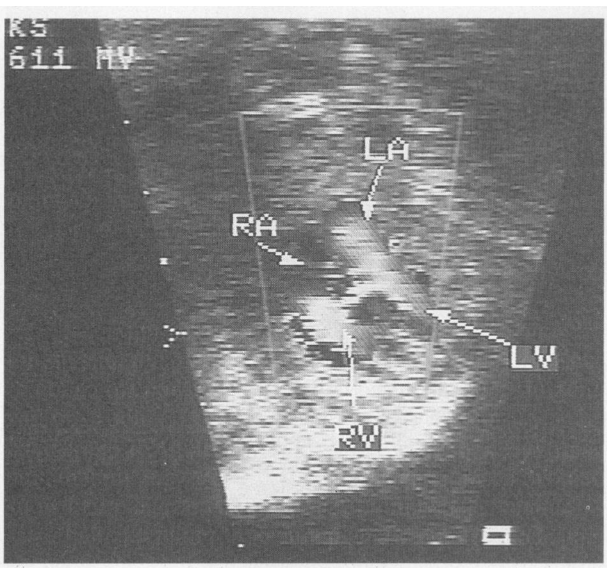

Figure 13.—A 4-chamber view of a ventricular septal defect is shown. The right atrium **(RA)**, right ventricle **(RV)**, left atrium **(LA)**, and left ventricle **(LV)** can be seen lying within the fetal thorax. The Doppler color flow information is represented in black and white, but clearly shows flow between the two ventricles related to a ventricular septal defect.

a dysplastic, immobile aortic valve or with a nearly normal left ventricle but with poor ventricular function, mitral regurgitation, and severe endocardial fibroelastosis. We have seen three cases of mitral valve stenosis or atresia and one with Shone's complex (parachute mitral valve, a single left ventricular papillary muscle, bicuspid aortic valve, and atrial and ventricular septal defects). One fetus died prenatally, and another was born with the CHARGE* association and died at 3 months. In addition, we have seen five fetuses with a single atrioventricular connection. Three had an absent left atrioventricular connection, with a double-outlet right ventricle and arch

*The CHARGE association is a complex of defects including **C**oloboma, **H**eart defects, choanal **A**tresia, mental **R**etardation, and **G**enital and **E**ar anomalies.

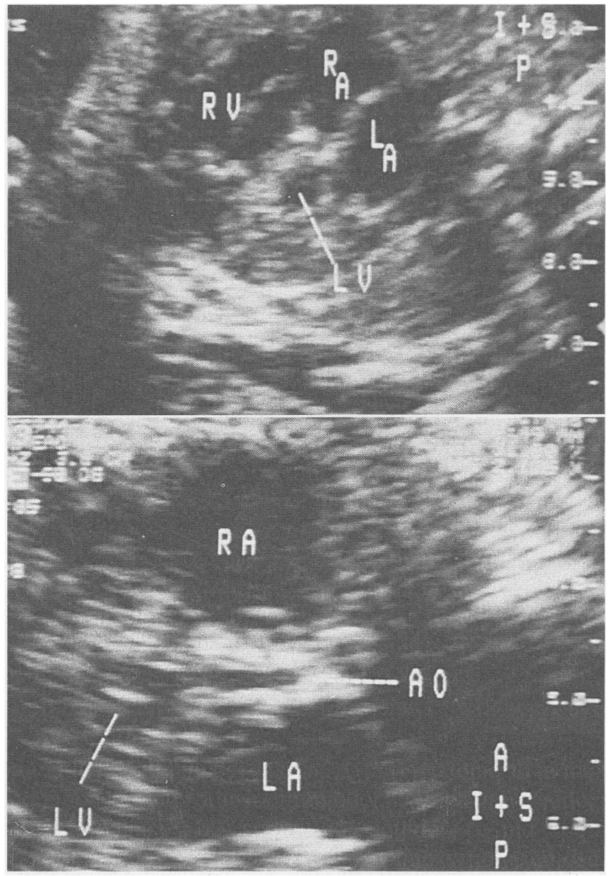

Figure 14.—A view of a hypoplastic left heart was taken in a patient at 30 weeks' gestation and referred because the obstetrician had noted an enlarged left atrium. The top frame, taken in a 4-chamber view, shows a minute left ventricle **(LV)** with a thickened endocardium. The other chambers, right atrium **(RA)**, right ventricle **(RV)**, and left atrium **(LA)**, can be identified. In the bottom frame, in an equivalent to a parasternal long-axis view, the minute left ventricular outflow tract and hypoplastic ventricle are identified. There appears to be no continuity between the aorta **(Ao)** and the left ventricle (from Schmidt and Silverman[49]).

anomalies, whereas one had an absent right atrioventricular connection and transposition. None of these infants survived beyond the first month of life.

Various forms of right heart abnormalities can be diagnosed. We have seen eight patients with severe pulmonary valvar obstruction, either critical stenosis or atresia (Figure 15) (Table 1). Although postnatally these patients frequently have a small right ventricle, it may be larger than normal during early gestation.[60,61] Tricuspid regurgitation is always seen in these patients. Ebstein's anomaly of the tricuspid valve has been seen in seven patients (Figure 16). None survived the first week of life, with two dying in utero.[62,63] Significant risk factors have been seen frequently. One was the child of a woman with Ebstein's anomaly, one of a woman receiving large doses of lithium,[64] and one of a woman with diabetes mellitus; the last fetus also had skeletal anomalies.

Defects in the ventriculoarterial connection are not unusual. We have seen four fetuses with transposition of the great arteries and ventricular septal defect. Two had associated systemic malformations, namely omphalocele and diaphragmatic hernia. Truncus arteriosus was seen in three fetuses. One of these also had trisomy 13.[65] One has survived to undergo surgical correction after delivery. A total of 13 fetuses with forms of tetralogy of Fallot have been seen, including 7 with a double-outlet right ventricle and 2 with an absent pulmonary valve complex. These lesions have a higher rate of recurrence within families than other lesions; three of four fetuses with standard tetralogy of Fallot had immediate relatives with the same abnormality. They are also frequent in fetuses with midline anomalies, including diaphragmatic hernia, omphalocele, cleft lip and palate, holoprosencephaly, or ectopia cordis (Figure 17).

In each of three fetuses we have seen with thoracopagus, we could identify the major but not complete aspects of the disorder.[66,67] All have had major abnormalities and fusion at the ventricular level inconsistent with postnatal survival. The one woman who refused termination required a cesarean section for delivery of twins, who died shortly after birth.

Three cases of rhabdomyoma as an expression of tuberous sclerosis were encountered (Figure 18). Hydrops, occasionally found in these cases, may be related to hamartomas obstructing venous return or ventricular inflow.[68] A lesion in the ventricular septum in one fetus produced left ventricular outflow obstruction and left ventricular endocardial fibroelastosis. These lesions are the only prenatal expression of tuberous sclerosis; therefore, detection provides an important basis for the genetic counseling of parents who carry this gene.

Valvar stenosis can be readily identified in utero. Flow disturbance imaged with color flow mapping and

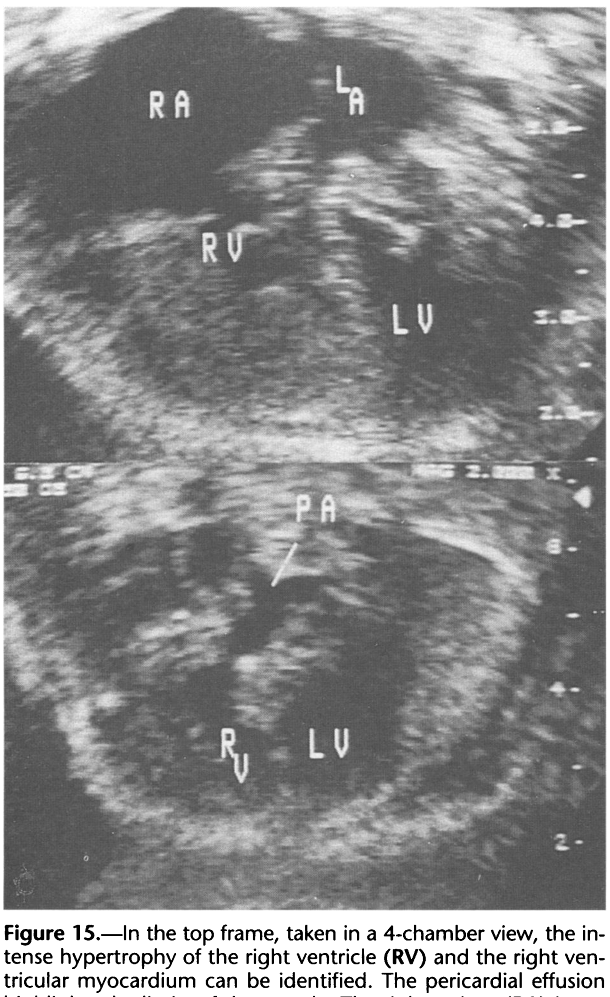

Figure 15.—In the top frame, taken in a 4-chamber view, the intense hypertrophy of the right ventricle **(RV)** and the right ventricular myocardium can be identified. The pericardial effusion highlights the limits of the muscle. The right atrium **(RA)** is enlarged and the right ventricular cavity small. In a cranially angulated 4-chamber view (bottom frame), bright echoes in the region of the pulmonary valve annulus can be identified. No forward flow was identified across the structure. The pulmonary artery **(PA)** bifurcation is shown. The endocardium of the ventricle appears bright (fibroelastosis) and the right ventricle appears hypertrophied (from Schmidt and Silverman[49]). **LA** = left atrium

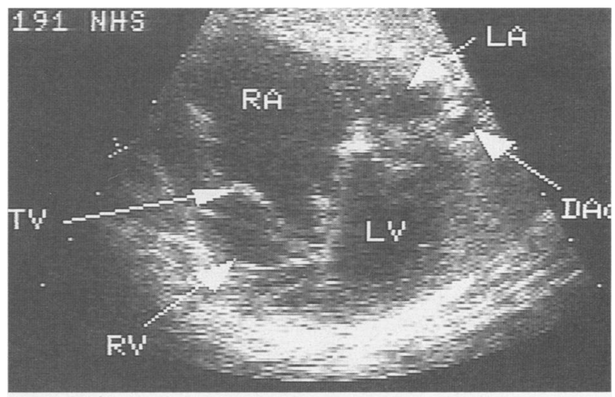

Figure 16.—Ebstein's anomaly is shown in a fetus at 30 weeks' gestation. The 4-chamber view shows a characteristic displacement of the septal leaflet of the fetal tricuspid valve **(TV)** and large sail-like anterior leaflet. The right ventricle **(RV)** appears diminished in size by the displacement of the enlarged right atrium **(RA)** (from Silverman, reprinted with permission[15]). **DAo** = descending aorta, **LA** = left atrium, **LV** = left ventricle

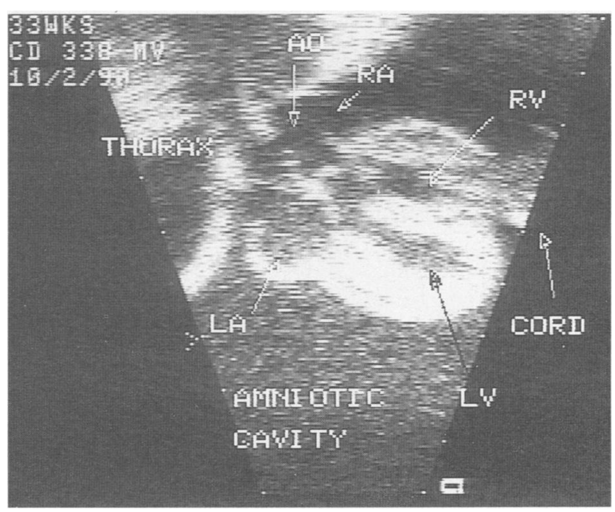

Figure 17.—A fetus is shown with ectopia cordis seen at 33 weeks' gestation. The entire heart is outside the chest wall in the amniotic cavity. All 4 cardiac chambers are seen next to the umbilical cord. In addition, there is a large superior ventricular septal defect between the right **(RV)** and left **(LV)** ventricles (from Silverman[15]). **Ao** = aorta, **LA** = left atrium, **RA** = right atrium

substantiated by continuous wave Doppler ultrasonography allows the gradient to be measured, even though the velocity is slow because of the low blood pressure in the fetus.

Diagnosis and Treatment of Fetal Cardiac Arrhythmias

Fetal arrhythmias are a common occurrence, with a frequency of approximately 15% in our series (Table 2).

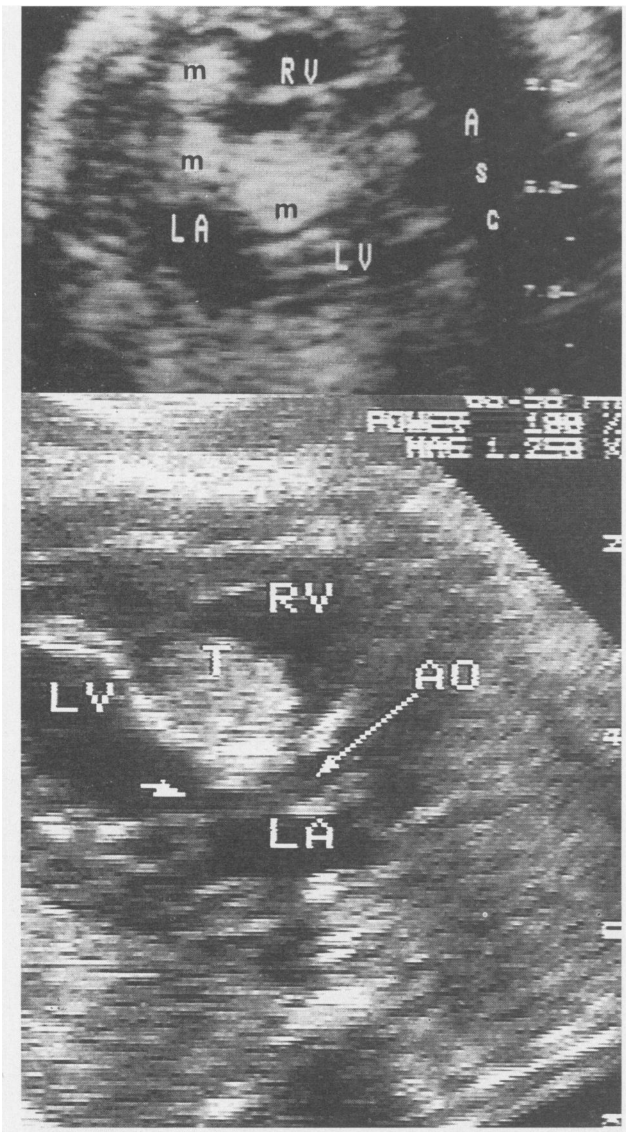

Figure 18.—Two ultrasonograms taken from a fetus with a rhabdomyoma show a pattern consistent with a diagnosis of tuberous sclerosis. In the top frame, the masses **(m)** appear to be in the apex, the free wall of the right ventricle **(RV)**, and protruding into the right atrium. The bottom frame shows a large tumor mass **(T)** within the ventricular septum and narrowing the left ventricular **(LV)** outflow tract. Note the brightness of the endocardium of the left ventricle, indicating endocardial fibrosis. The mass encroaches on the left ventricular outflow tract situated between the left ventricle and aorta **(Ao)**. This fetus was found to have endocardial fibroelastosis as a consequence of the left ventricular outflow tract obstruction at birth (from Schmidt and Silverman[48]). **LA** = left atrium, **LV** = left ventricle, **RV** = right ventricle

They can be difficult to diagnose because electrical events cannot be measured, only the mechanical result of these events. Therefore, the construction of ladder diagrams (Figure 19) is crucial to analyzing and understanding arrhythmias. Ladder diagrams, which allow a determination of the temporal sequence of atrial and ventricular contraction, are generally derived from M-mode or Doppler ultrasonography. Normally the atrial activity is followed by that of the atrioventricular node, which in turn is followed by contraction of the ventricle.

The most common arrhythmia seen in fetuses is isolated premature atrial contractions, accounting for two thirds of the arrhythmias in our series (Table 2). M-mode (Figure 20) or Doppler ultrasonograms (Figure 21) can easily see these premature beats. Premature atrial contractions are benign, usually transient, and do not require treatment.[18-24] Because caffeine, nicotine, chocolate, and other pharmacologically active substances can increase their frequency, abstinence from these is usually recommended. Isolated premature atrial contractions rarely progress to supraventricular tachycardia. Therefore, periodic monitoring of the fetal heart rate by the primary physician is essential, but repeat fetal echocardiography is rarely indicated.

Isolated premature ventricular contractions were much rarer than atrial contractions in our experience, but others have found them more frequently.[23] Differentiating atrial from ventricular premature beats can be difficult in a fetus. The most reliable method involves measuring the compensatory pause. The compensatory pause is a phenomenon seen in electrocardiography, caused by the resetting, or lack of resetting, of the sinus node. A complete compensatory pause occurs when the interval from the beat before the premature beat to the one after the premature beat is equal to the interval between two normal beats. A complete pause is more commonly associated with premature ventricular contractions (Figure 22), whereas premature atrial contractions generally have an incomplete compensatory pause; that is, the interval is less than two normal beats.

Fetal tachyarrhythmias are common, accounting for 15% of all arrhythmias in our series. Most common is a supraventricular tachycardia (Figure 23). Though this may be tolerated for extended periods, it can lead to car-

TABLE 2.—*Fetal Arrhythmias Detected by Ultrasonography**

Arrhythmia	*Fetuses, No.*	*Treated, No.*	*Neonatal Survivors*
Premature atrial contraction	190	--	189
Premature ventricular contraction	3	--	3
Supraventricular tachycardia	17	16†	16
Atrial flutter	5	5‡	5
Complete heart block	19	2§	11

*From Silverman.[15]

†Effective treatment: digoxin alone in 11, digoxin and verapamil in 2, flecainide in 2, and digoxin and procainamide hydrochloride in 1.

‡Effective treatment with digoxin alone in all except 1 fetus, controlled with digoxin, quinidine sulfate, and verapamil.

§In 1 fetus with heart block, fetal placement of a pacemaker was only successful for a short time, and the fetus died during the operation.

diac failure, fetal hydrops, and fetal demise. Stroke volume is usually decreased during tachycardia; this can be seen by examining the Doppler signal in the umbilical cord (Figure 24). Atrial flutter usually presents with varying degrees of atrioventricular block (Figure 25) and also with hydrops due to cardiac failure.

The treatment of tachyarrhythmias depends on the age of the fetus. The preferred course is to deliver the fetus because treatment is much safer and more reliable after birth. If delivery is not indicated because of other factors, intrauterine treatment may be required. Medication administered to the fetus by giving it to the mother usually is effective[18,19,26,69-71] and therefore is the treatment modality of choice. Direct administration to the fetus is rarely indicated.

Digoxin has been the drug of first choice.[18,19,70-72] If it fails to convert the fetal heart rate to sinus rhythm, we additionally use flecainide acetate, verapamil, propranolol

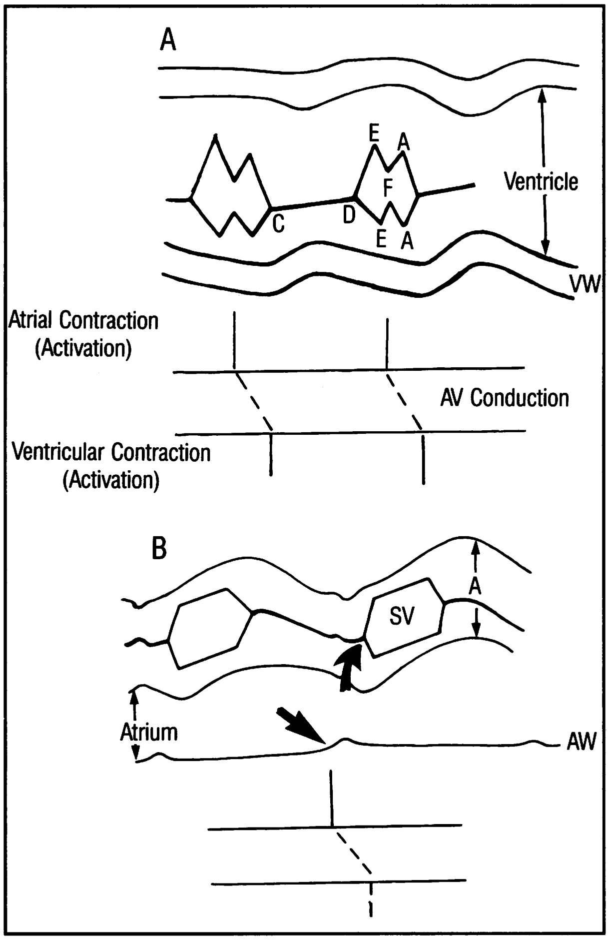

Figure 19.—The schematic representation shows the motion of cardiac structures that may be seen by M-mode echocardiography and ladder diagrams obtained from these recordings. **A,** This depicts the ultrasound beam passing through a ventricle and an atrioventricular **(AV)** valve within it. The atrioventricular valve leaflets can be seen opening in early diastole (D-E portion), moving towards each other in mid-diastole (E-F), and moving away from each other again in late diastole during atrial contraction (F-A). The beginning of this second opening (F point) indicates the onset of atrial contraction. The closure of the valve leaflets (C point) or the beginning of forward motion of the posterior ventricular wall **(VW)** indicates the onset of the ventricular contraction. The ladder diagram (below) marks these events; the delay between atrial and ventricular activation is the atrioventricular conduction time. **B,** This shows the ultrasound beam passing through the root of a great artery **(A)**, in this case the aorta and the semilunar valve within it, then through an atrium behind that vessel. The M-mode recording shows the onset of forward motion of the atrial wall **(AW; lower arrow)**, which defines the beginning of atrial contraction. The opening of the semilunar valve **(SV, curved arrow)** defines the beginning of the ventricular contraction. The ladder diagram (below) demonstrates these events as in A (from Schmidt and Silverman[48]).

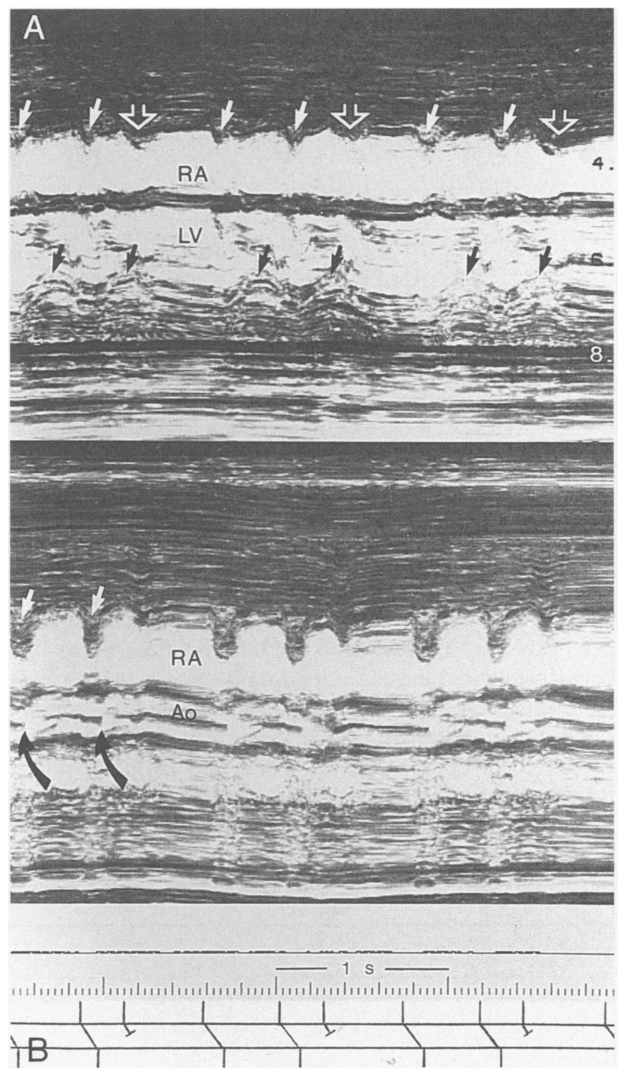

Figure 20.—An M-mode evaluation is shown in a fetus with premature atrial contractions. **A,** In the top frame, the ultrasound beam passes obliquely through the heart and shows the right atrium **(RA)** and left ventricle **(LV)**. Normal atrial beats **(white arrows)** are followed by ventricular contraction **(black arrows)**, but the ectopic beats **(open arrows)** do not result in ventricular contraction. The bottom frame confirms that the ectopic beats are blocked. Normal atrial contractions **(white arrows)** are followed by aortic valve opening **(black arrows)**, but the ectopic beats are not. **B,** The ladder diagram shows the schematic representation of blocked premature atrial contractions. The top line is the atrium, the middle the atrioventricular node, and the bottom the ventricle (from Schmidt and Silverman[49]).

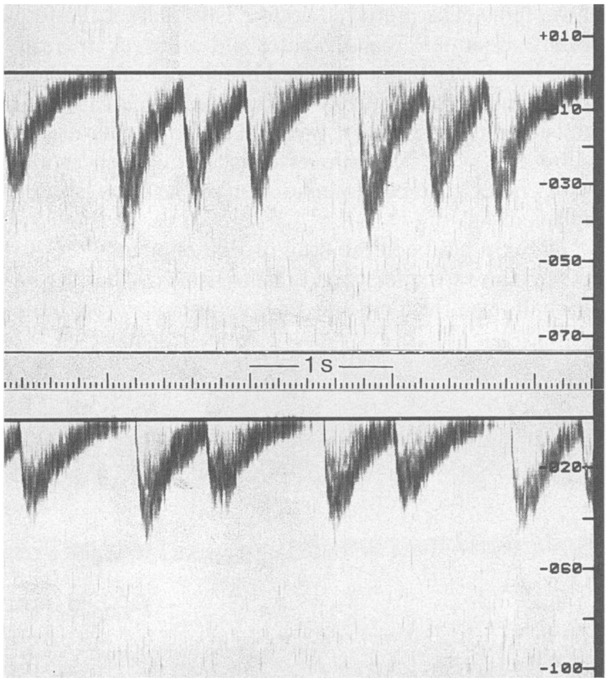

Figure 21.—An example of group beating is shown associated with premature atrial contractions as seen from the umbilical cord artery. In the top row, the group beating appears to be three beats followed by a pause and three beats followed by a pause; in the lower panel, it is two beats followed by a pause and two beats followed by a pause. The premature atrial contraction is ineffective at creating a contraction that allows umbilical arterial pulsation, identified as a pause. What is clear, particularly from the top tracing, is that the pause is an incomplete compensatory pause and therefore is a supraventricular premature contraction.

hydrochloride, or procainamide hydrochloride, in that order (Table 2). The dosage schedule for these drugs has been formulated based on loading doses for the conversion of cardiac arrhythmias in adults (Table 3). Antiarrhythmic drugs are administered intravenously in a delivery room, except for digoxin, which may be given orally. Rapid obstetrical intervention, if needed, should be conveniently located and available. During such cardioversion, the fetal heart should be directly monitored using echocardiography. During pregnancy, enteral absorption of digoxin may be limited, and additional administration of other drugs such as verapamil may decrease its clearance[69]; therefore, maintenance therapy should be controlled by monitoring maternal serum concentrations. Other drugs have been successful for converting supraventricular tachycardia.[71] Except for digoxin, treatment is best administered in a tertiary-care facility with complete support personnel because side effects for the mother or fetus may result.

Several mechanisms, including the frequent occurrence of nonconducted premature atrial contractions, group beating, or complete heart block, may lead to prolonged fetal bradyarrhythmia. We have observed group beating with bradycardia and junctional or ventricular escape beats. Doppler ultrasonography is valuable for distinguishing these conditions.

Heart block can be recognized using M-mode echocardiography, Doppler ultrasonography, or even Doppler color flow mapping (Figure 26). In 15% of our cases with fetal arrhythmia, bradyarrhythmia due to complete heart block was present. Structural heart defects are more common in fetuses with complete heart block, particularly when nonimmune hydrops is present, but heart block can be an isolated finding. Isolated complete heart block usually occurs in women with autoimmune connective tissue disease. Certain antibodies (anti-Ro[SS-A] and anti-La[SS-B]) can cross the placenta and have been found in affected newborns.[42,72] The prognosis in patients with isolated heart block, with or without documented autoimmune disease, is fair. Many fetuses can survive to delivery without serious hydrops. Those with associated congenital heart disease, however, almost invariably die of hydrops in utero or shortly after birth.

There is currently no effective therapy for infants with symptomatic heart block. Variable results have been reported with the β-agonists ritodrine and terbutaline sulfate. We were once able to raise the heart rate from 47 to 57 beats per minute in a 27-week fetus and continue the

TABLE 3.—*Dosage Schedule for Antiarrhythmic Transplacental Treatment**

	Loading		*Maintenance*			*Plasma Level*	
Drug	*Dose, mg*	*Route*	*Dose, mg*	*Route*	*Interval, hr*	*Therapeutic*	*Toxic*
Digoxin	0.5 (initial) + 0.25 q 6 hr†	Intravenous	--	--	--	--	--
	or						
	1.5-2 (in 24-48 hr)	Oral	0.25-0.75	Oral	24	1-2 ng/ml	>2.5 ng/ml
Verapamil‡§	0.1-0.2/kg	Intravenous‖	80-120	Oral	6-8	80-300 ng/ml	>300 ng/ml
Propranolol HCl	0.1-0.2/kg	Intravenous	10-40	Oral	8-6	50-100 ng/ml	--
Procainamide HCl	15/kg#	Intravenous¶	0.5-1.0 grams	Oral	4	3-6 μg/ml	>8 μg/ml
Quinidine sulfate	--	Oral only	0.3-0.4 grams	Oral	6-8§	2-6 μg/ml	>8 μg/ml
Flecainide acetate	--	--	100-150 2x/d		To add		

HCl = hydrochloride

*From Silverman.[15]
†Total: 1.25 to 1.5 mg.
‡Do not use verapamil and propranolol HCl at the same time!
§Atropine sulfate, 0.5 to 1 mg, should be on hand for managing the side effect of maternal or fetal bradycardia due to atrioventricular block.
‖Should be given over a period of 1 to 2 minutes.
¶As infusion, about 50 mg per minute.
#Maximum of 1 gram.

pregnancy to 36 weeks. After birth a permanent pacemaker was successfully implanted. Direct fetal pacing using an amnioscope has been unsuccessful at preventing fetal demise.[73] The fetal treatment group at the University of California, San Francisco, has developed and tested direct fetal pacing, placed through a hysterotomy, in animals. It has been attempted in one fetus with hydrops and a heart rate of 48 beats per minute. The fetus, however, had poor cardiac function and atrioventricular valve regurgitation before the operation and died during implantation of the pacemaker, despite capture and an increase in the heart rate. Indications for such an invasive treatment would be a heart rate of less than 55 beats per minute with hydrops fetalis and the absence of congenital heart disease.

In the overall assessment of fetal arrhythmias, isolated irregular beats are of little concern. Irregular beats associated with runs of tachycardia or bradycardia are of more concern, and a heart rate of more than 200 or less than 80

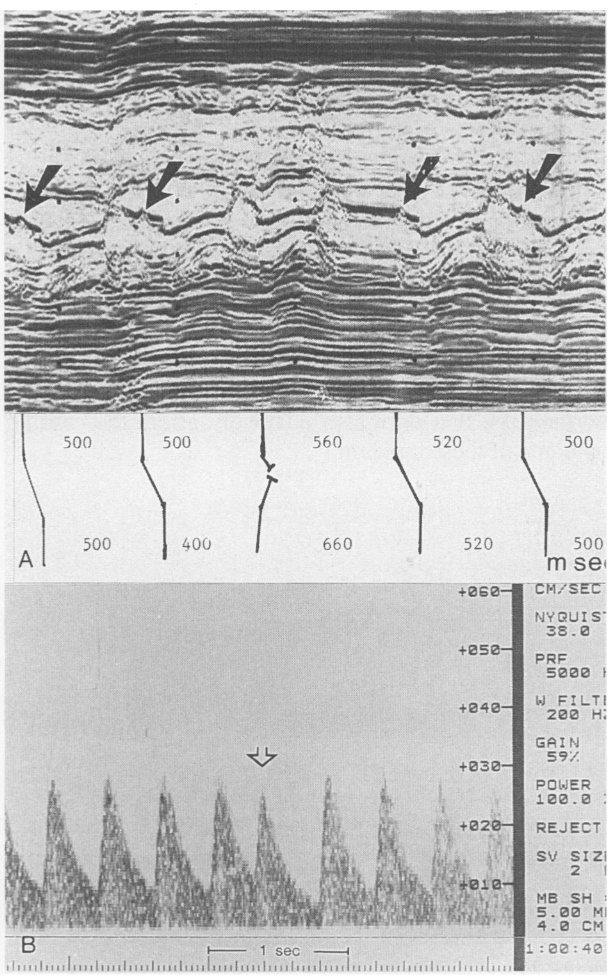

Figure 22.—An M-mode evaluation is shown in a fetus with premature ventricular contractions. **A,** The mitral valve movement and that of the left ventricular posterior wall can be seen. Normal beats are preceded by an atrial kick seen on the mitral valve echo **(arrows)**; the premature third beat has no atrial kick. In addition, the subsequent beat is delayed, resulting in a complete compensatory pause, because 2 intervals of regular beats also last about 1,020 mseconds as seen in the ladder diagram between sections. This favors the diagnosis of a ventricular contraction. **B,** A pulsed Doppler ultrasonogram was done within the umbilical artery in a different fetus and shows the hemodynamic consequence of premature beats. The premature beat **(open arrow)** has a smaller stroke volume and is followed by a complete compensatory pause; therefore, it is more likely to be of ventricular origin (from Schmidt and Silverman[49]).

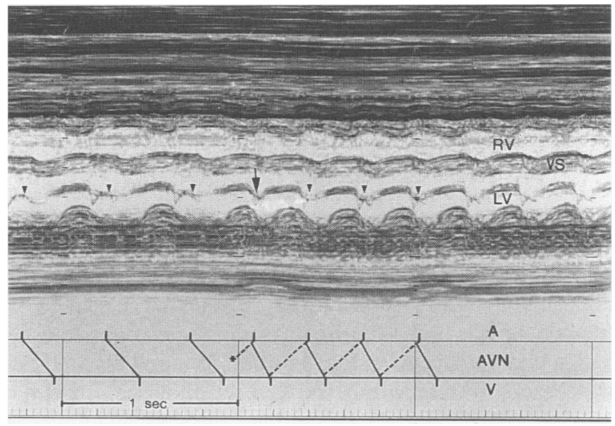

Figure 23.—An M-mode recording is shown of a 30-week fetus with a supraventricular tachycardia. This example demonstrates the reentry mechanism of the tachycardia. To the left of the recording is normal sinus rhythm; note that the atrial kick **(small black arrowheads)** on the mitral valve echo indicating atrial contraction is fairly separated from the preceding valve movement during early diastolic filling. After 3 regular beats, a premature atrioventricular nodal depolarization causes retrograde atrial and antegrade ventricular activation, thus starting a reentry cycle. The first atrial kick on the mitral valve echo appears at the same time as the early diastolic filling deflection **(large black arrow)**; during the tachycardia it then can be seen in a different position located closer to the early filling wave than during sinus rhythm (from Schmidt and Silverman[49]). **A** = atrial contraction, **AVN** = atrioventricular node activation, **LV** = left ventricle, **RV** = right ventricle, **V** = ventricular contraction, **VS** = ventricular septum

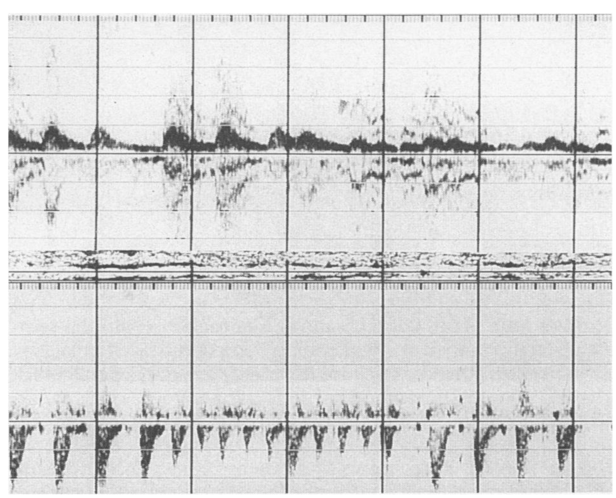

Figure 24.—A pulsed Doppler interrogation within the umbilical artery **(top)** and the pulmonary artery **(bottom)** is shown taken of a fetus with supraventricular tachycardia. The reduction in stroke volume during tachycardia, followed by a pause and resumption of normal sinus rhythm, is clearly seen in the lower panel. Horizontal lines represent Doppler velocities of 0.25 per millisecond; vertical lines are time markers (1 sec) (from Schmidt and Silverman[48]).

beats per minute requires further evaluation. Structural heart disease in patients with isolated irregular beats or with tachycardia is not as common as in patients with complete heart block.

Discussion

Outcome After Fetal Echocardiography

Our series (Table 1) confirms that the overall outcome of a fetus with a structural cardiac abnormality is unfavorable.[10,13,27,38,60,74] Eight pregnancies were terminated electively, two because of severe fetal cardiac defects, the others because of chromosomal abnormalities. There were 30 fetal or neonatal deaths, 4 fetuses are not yet born, and only 11 children (23%) were alive at the end of the neonatal period. Of the 11 infants, 4 underwent a cardiac operation within the first months of life, including 1 who had cardiac transplantation. In those cases presenting with nonimmune hydrops and cardiac defects, the incidence of fetal death was high (16 of 18 cases). Ten of these fetuses had severe atrioventricular regurgitation, and all died either before birth or within the first week of life. Eight fetuses had cardiac defects coupled with complete atrioventricular block, seven of which died prenatally or in the neonatal period. The prognosis for fetal survival appears poor in the presence of structural abnormalities coupled with atrioventricular valve regurgitation, complete heart block, or fetal hydrops. The reader should note that because fetal cardiac ultrasonography is in its early stages of development, those defects most likely to be symptomatic are more likely to have been recognized.

In the large series published by Smythe and co-workers involving 3,016 fetuses, 170 were found to have heart disease.[38] Of the 170 fetuses, 55 (32%) had major extracardiac malformations and 45 (26%) had chromosomal abnormalities. Elective termination was chosen by 77 (45%) of these patients. Of the 93 continuing pregnancies, 15 (16%) resulted in a stillborn and 43 infants (46%) died postnatally. In the cases of nonimmune hydrops with a cardiac basis, all proved fatal. In all, 35 (38%) of the 93 continuing pregnancies survived. This group found, as did our group, that the spectrum of cardiac anomalies presenting before birth was different and more severe than the spectrum that presented after birth and that the outcome of the pregnancies was less favorable than for a group of infants with heart disease occurring postnatally. Presumably this relates in some way to the reasons for the referral for an echocardiographic examination, including the high incidence of chromosomal and extracardiac abnormalities, that may also adversely affect the cardiac outcome of these children.

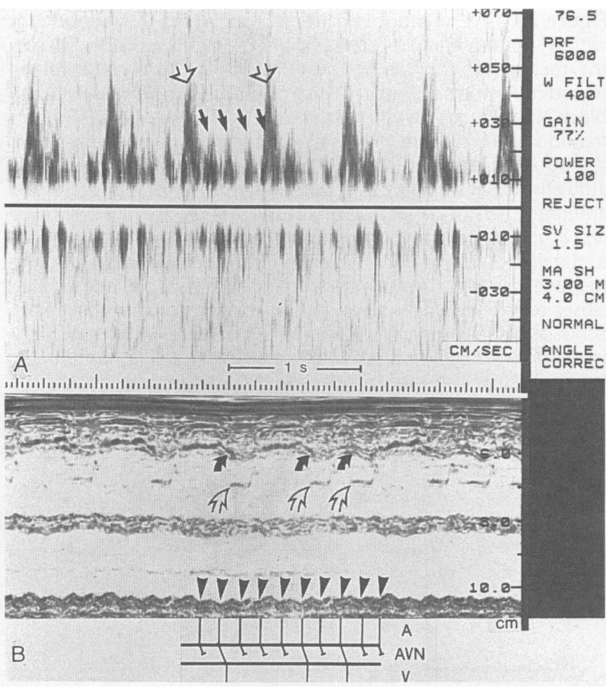

Figure 25.—Atrial flutter with atrioventricular block is shown in a 36-week fetus. **Top,** Pulsed Doppler interrogation with the sample volume placed in the descending aorta and the left atrial wall demonstrates atrial contractions (smaller flow signals, **small black arrows**) and ventricular contractions (bigger flow signals, **open arrows**). In this recording there is constantly a 4:1 atrioventricular block. This results in an apparently regular heart rate of about 100 per minute. **Bottom,** An M-mode recording from the same fetus shows rapid atrial contractions with a rate of 400 beats per minute **(black arrowheads)**. Ventricular activation is inferred from either tricuspid valve closure **(open arrows)** or the onset of ventricular wall motion **(black arrows)**. The ladder diagram demonstrates the presence of 4:1 atrioventricular block on the left side with one following beat showing a 2:1 block. These varying degrees of atrioventricular block result in an irregular heart rate (from Schmidt and Silverman[48]). **A** = atrium, **AVN** = atrioventricular node, **V** = ventricle

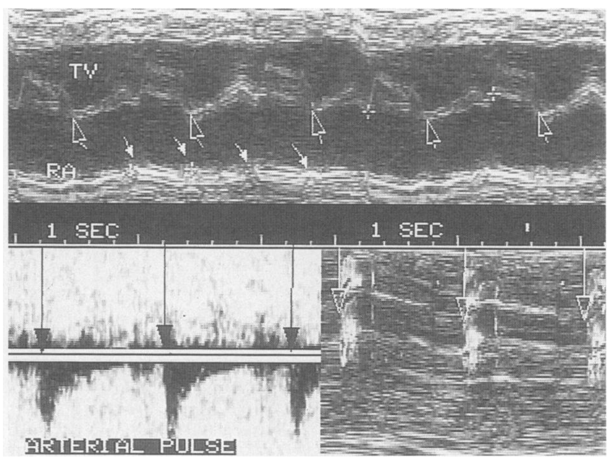

Figure 26.—A composite collection of methods is shown for recognizing complete heart block. **Top,** An M-mode strip is shown through the right ventricular wall anteriorly, the tricuspid valve **(TV)** in the middle, and the right atrial wall **(RA)** posteriorly. The scale markers indicate 1-second large divisions and 0.2-second small divisions from the opening of the tricuspid valve **(large open arrows)**. The ventricular rate can be assessed at 55 beats per minute. The contractions shown on the atrial wall **(small closed arrows)** indicate a rate of 150 beats per minute. This atrioventricular dissociation indicates complete heart block. **Bottom left,** A Doppler recording from the pulmonary artery confirms the slow ventricular rate at 55 beats per minute. The arrows indicate the onset of ejection. **Bottom right,** A Doppler color flow M-mode tracing is done through the pulmonary valve. The Doppler color flow information is shown in black and white, but indicates the onset of ventricular flow **(open arrows)** at the same rate.

In one instance, the administration of betamethasone to improve the lecithin-sphingomyelin ratio caused a dramatic resolution of a serous effusion in heart block related to collagen vascular disease. Such a resolution would indicate these effusions were not on the basis of cardiac failure, but rather were a further expression of the effect of the transplacental antibodies.

Diagnostic Errors

Despite the resolution of current ultrasound equipment, errors in interpretation are possible. In our series, we made the false-negative diagnosis of a structurally normal heart in four fetuses: one each with a ventricular septal defect, aortic coarctation coupled with double-orifice mitral valve, mild pulmonary stenosis, and situs inversus (mirror-image dextrocardia). The last error, made early in our experience, should not be made if the correct position of the heart in the chest is determined first; subsequent cases of situs inversus in our series have been correctly recognized prospectively. In complex cardiac defects, the main lesion may be recognizable, but unless careful attention is paid to the entire examination, secondary lesions might be missed. In general, experience suggests that prenatal findings in complex congenital abnormalities tend to underestimate the spectrum of abnormalities.

Both false-negative and false-positive findings have been reported previously.[10,11,17,74] We found that most of the serious errors were made when using older equipment that had poorer resolution, when magnification was not possible, and when the Doppler technique was not used. Errors unrelated to equipment and beyond the ultrasonographer's control include such technical factors as suboptimal imaging, which occurs with gross maternal obesity, polyhydramnios, or unfavorable fetal positioning. The resolution of echocardiographic imaging is limited to distances of 1.0 to 1.5 mm, which may make imaging structural abnormalities such as relatively small ventricular septal defects technically impossible. Mild aortic or pulmonic stenosis may be difficult to detect, because valve structural features may not be resolved accurately enough to determine minor valve abnormalities, and blood flow velocity may be lower than after birth due to low ventricular pressures present in fetal life. Other defects such as mild aortic coarctation[75,76] or a secundum atrial septal defect may be indistinguishable from normal anatomy in a fetus. Furthermore, cardiac lesions may develop or worsen later in pregnancy, as we have observed in cases of cardiomyopathy, and will be detected only if serial studies are done. We have made it a practice to restudy fetuses later in gestation when there is doubt as to whether the study is normal. On the other hand, some lesions may disappear on subsequent studies, such as ventricular septal defects that close spontaneously.

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